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ENERGY EFFICIENCY IN STOCK PREPARATION RECYCLED FIBER BROWN

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ABSTRACT

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Recycled fiber is widely used nowadays in the forest resource lacking country, but the challenge is that the recycled fiber is not as clean as virgin fiber. In order to meet defined fiber quality before sending to paper machine approach system, stock preparation is needed. The recycled fiber studied in this thesis is old corrugated container, which is a popular raw material in brown fiber utilization.

This study was held in a paper mill in China which consumed OCC as raw material. The separation processes' energy efficiency were analyzed in this paper. The separation processes here referred to screening, fractionation and centrifugal cleaning. Exploring the pumping system and screen motor energy efficiency was the main focus of this thesis. By the end of the study, the recommendation of the pumping system and potential cost-saving expectation was provided.

In this paper, totally 9 separation processes including 24 pumps, 12 screens were investigated. During the investigation period, all the equipment were running in a normal condition without major problems except slightly higher energy consumption than optimized OCC line. A mathematical calculation was used to evaluate the efficiency. According to the analysis, most of the pumps and screens were running at a moderate efficiency.

Nevertheless, there were pumps that could be further improved to save energy. In order to predict the energy saving potential of pumps, the total dynamic head was introduced to compute the optimized pump efficiency. At the end of the study, it was found that there was a window of opportunity to improve the pumping system energy efficiency. If the stock preparation system would run under the desired condition, there could be hundreds thousands euro savings annually.

Energy consumed in stock preparation system is electrical energy generated by power boiler which burns coal as fuel. As a nonrenewable natural resource, it will not only increase environmental burden but it is also against sustainable development. Although there are alternatives to fossil fuels, cutting electricity consumption from its origin (e.g. lower the equipment energy consumption) is also a good measure to both economy and environment.

Key words: OCC, recycled fiber, fiber separation, energy efficiency, pump

CONTENTS

ABBREVIATIONS

OCC	Old Corrugated Container
HD	High Density
LW	Light Weight
LC	Low Consistency
SF	Short Fiber
MF	Medium Fiber
LF	Long Fiber
PMA	Paper Machine Approach
MD	Machine Direction
CD	Cross-machine Direction
BDMTPD	Bone Dry Metric Ton per Day

1 INTRODUCTION

Recovered paper is globally the most important raw material in paper and board industry. North America, Japan and Europe are the most important recovered paper resources. Recovered paper is mainly exported to Asia, especially China. (Ulrich & Samuel. 2009) In 2016, China consumed 63,29 million tons recycled fiber, where 23,08 million tons were imported. When comparing with total pulp consumption including virgin fiber, the recycled pulp represents 80% of it. (China Paper Association. 2017) There are many different equipment, pumps and motors that it is important to size and optimize systems properly.

The aim of this work is firstly to discuss the general recycled fiber accessibility in paper industry and secondly describe the OCC line stock preparation process according to the case in the selected mill. Since on-site data collection is performed in this study, the energy performance in each process will be analyzed and possible energy saving recommendation is presented in chapter 4. This study is meant to give a better understanding of selected pulp line energy efficiency in a cost-effective manner while keeping the quality of paperboard manufactured.

Energy efficiency in a pulp line refers to a lower energy consumption to produce the same amount of pulp while keep the same quality. Energy efficiency improvement is an important measurement to save energy costs and to increase profit margin. There are various indicators that can be used to illustrate production efficiency. In this case energy consumption per ton of handling amount was chosen as the cost effectiveness indicator for the production efficiency evaluation. (Fracaro. Vakkilainen. Hamaguichi. Souza. 2012)

The study was carried out in Chinese paper mill which uses OCC as their main furnish in the paperboard production. The scope of this thesis work is limited to separation processes in stock preparation. Those processes refer to DuoClean system (HD cleaning), coarse screening, fractionation, short fiber low consistency cleaning, long fiber low consistency cleaning, long fiber fine screening, long fiber light weight cleaning, medium fiber low consistency cleaning and medium fiber light weight cleaning.

The main focus in this paper is on energy consumption in above mentioned processes, which electrical energy consumption is based on electricity consumed in the pumps and motors. During the research period it was found out that there is still possibility to improve efficiency. The optimization of pumping system was evaluated by using mathematical formulas shown in chapter 3. As a result of this study, it is possible to save energy over 600 kWh by optimizing pumping systems.

2 RECYCLED FIBER STOCK PREPARATION

2.1 Overview of recycled fiber

A single fiber, virgin and recovered, begins its life in the forest. It can be the fiber of rattan, bamboo, straw, bagasse, etc. But nowadays, wood fiber had been widely used as raw material worldwide. Regions lacking forest resources have to rely on the recycled fibers and other fiber sources other than wood virgin fiber. Fortunately, paper is one of the most recycled products in the world which gives fiber more or less a new life. The recovery rate for used paper had increased dramatically since 1990. Europe achieved 72% paper recycling rate which is the highest worldwide (Twosides. 2015). Recycled paper is expected to increase up to 61% of total global fiber supplies over next 10 years (Twosides. 2015). Figure 1 shows the generic fiber life cycle. There is a high possibility for a single fiber during its path through the cycle. In each stage there are the main streams to the next phase, additionally several side paths. It should be noted that fiber losses is unavoidable but it can be minimized during the process. (Ulrich & Samuel. 2009)

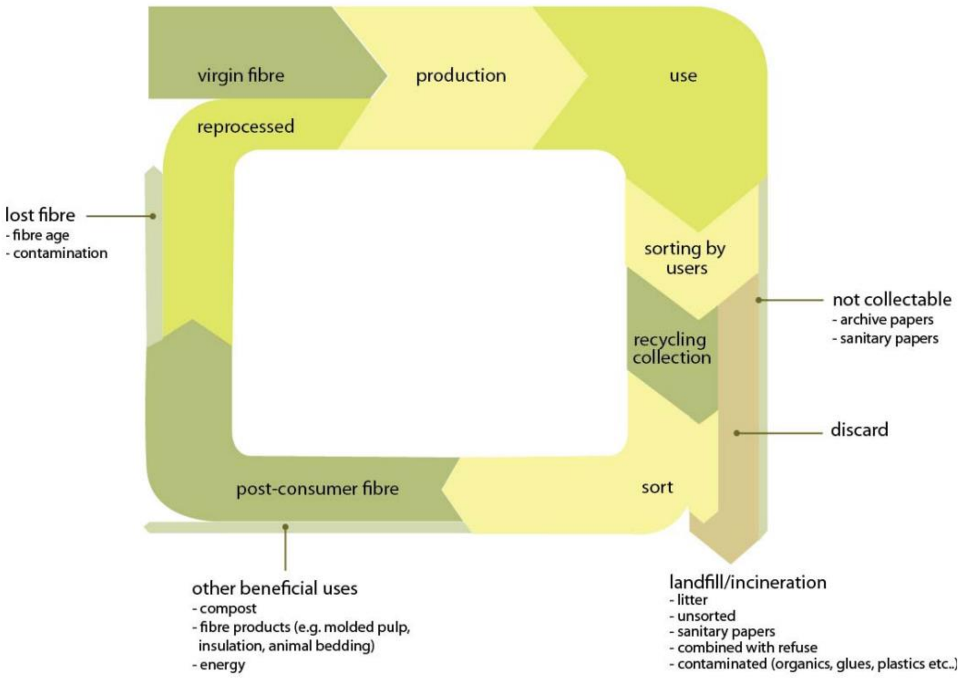

Figure 1. Generic fiber life cycle (Environment Canada. 2011, according to Paper Environment. 2013)

Recycled fiber generally require less total energy than virgin fiber. Traditional virgin fiber pulping could create major environmental burdens, including the production of greenhouse gases, overuse of natural resources, social and environmental impacts and so on. By using recycled fiber, these impacts could be reduced dramatically. (Kinsella. 2012)

In Chinese market, the total virgin fiber consumption has decreased every year since 2007, which means recycled fiber is the most favored raw material nowadays (shown in Figure 2). And already since 2015, the amount of recycled fiber account for 80% of total fiber consumption in China.

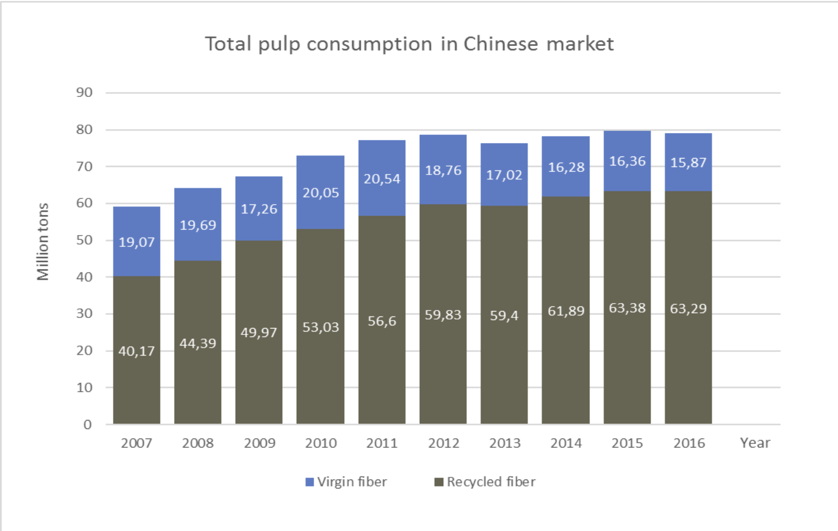

Figure 2. Total pulp consumption in Chinese market from 2007 to 2016 (China Paper Association. 2017)

Although recycled fiber is the most favored fiber resources in China, there are challenges during the application. One of the challenge is fiber shortening. As the recycling rate increase, fiber shortening would be more significant but the grade-based paper classification remains the same. Moreover, recovered paper contains a considerable non-fibrous material. The non-fibrous material lowers paper yield and deteriorates quality of paper and in the meantime, increases handling costs. (Karänen. Retulainen. 2016)

2.2 Stock preparation system in general

Similar to virgin fibers, OCC stock must meet defined quality criteria before feed to paper machine. Quality refers to the fiber characteristics, and to additives and non-fibrous contaminants. Consequently, the mixture has to be processed in various ways to meet the quality criteria for the paper to be produced. (Ulrich & Samuel. 2009) In order to achieve the desired stock quality, stock preparation system is introduced.

The stock preparation system consists of mechanical treatment of the stock before paper machine approach system. It begins with re-pulping or dilution of pulp and ends at the machine chest. (Paulapuro. 2007) Stock preparation system has several processes that are adapted to one another. The object of stock preparation system is to separate the non-fibrous contaminants that have negative effect on paper qualities to meet the desired fiber criteria. (Paper Academy. ND.)

According to the used mechanisms, the separation processes in stock preparation systems consist of screening, cleaning, flotation, washing and fractionation. Besides, pulping, deflaking, dispersing, refining, dewatering and bleaching also play an important role in recycled fiber stock preparation which vary according to the demand. (Ulrich & Samuel. 2009) In this paper, only screening, centrifugal cleaning and fractionation processes are going to be discussed.

2.2.1 Recycled fiber screening

The aim of screening is to separate solid contaminants particles from OCC pulp according to different particle size, shape and deformability as fibers (Paper Academy. ND.). During screening, the pulp suspension is forced through holes or slots that are larger than fibers but smaller than most of the detrimental particles.

First screening process in OCC line is coarse screening. It removes comparatively large cubical or spherical contaminants from pulp. After coarse screening there is typically fine screening process for the removal of smaller and more flexible non-fibrous particles. (Convergence Training. ND) The separation in fine screening is more complex. (Ulrich & Samuel. 2009)

Fibers sometimes also need to be classified according to their length. This kind of separation is also handled by screening. It is called fractionation. (Ulrich & Samuel. 2009) In one stage fractionation, short fiber is accepted to short fiber LC cleaning and/or thickening while long bier is rejected to LC and LW cleaning followed by fine screening and thickening. Alternatively rejects can be re-fractioned in second stage fractionator which accepts medium fiber to LC and LW cleaning followed by thickening and long fiber to LC cleaning, followed by fine screening, LW cleaning and thickening.

2.2.2 Recycled fiber centrifugal cleaning

Centrifugal cleaners, also known as hydrocyclones, are designated by their type of rejects. Cleaners used to remove contaminants with specific gravity greater than 1.0 such as sand, metal and stone are known as forward cleaners. Cleaners which remove contaminants with specific gravity less than 1.0 such as waxes and plastics are called reverse or light weight cleaners. Reverse centrifugal cleaners operate best at consistencies less than 1%. The paper industry has used centrifugal cleaners to separate heavy and light weight contaminants. (TIP 0508-10. 2000)

A centrifugal cleaner separates and removes non-fibrous components from pulp slurry by using rotational fluid motion to utilize differences in size, shape and density between fibers and undesirable materials. There are three significant forces (Figure 3) exerted on the pulp slurry, they are centrifugal force, drag force and buoyancy. Using centrifugal fields generated by cleaners, dense particles forced to the downstream while the light particles migrated to the central air core. The greater the difference between the pulp slurry and contaminant densities, the more probably the contaminants will be removed. (TIP 0508-10. 2000)

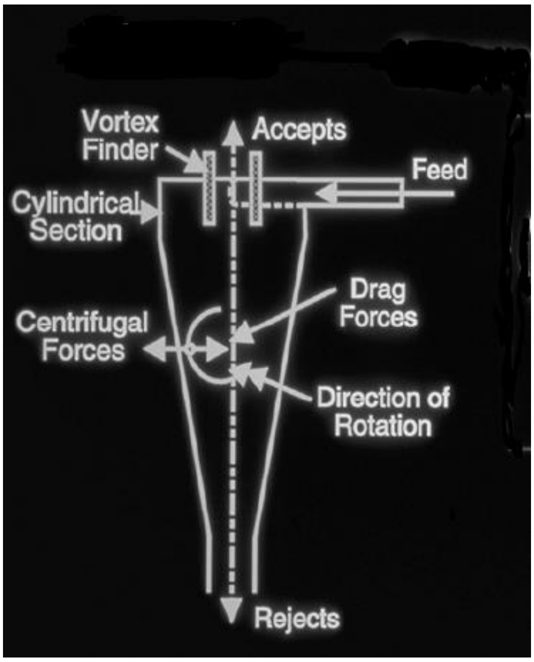

Figure 3. Centrifugal cleaner separation principle (TIP 0508-10. 2000)

Cleaners' operation principle is relatively simple and it is widely used in pulp and paper industry. Cleaners can be used in several positions in stock preparation systems. More often, the first position for cleaners is after pulping. (Ulrich & Samuel. 2009) Cleaners' design and material normally vary from applications. It is dependent on process consistency, temperature and wear conditions.

2.3 Stock preparation in the mill

In this mill, OCC was used as main furnish to manufacture testliner. The stock preparation system was built in an energy saving layout with most of the separation equipment installed on the basement floor.

2.3.1 OCC as raw material

Old corrugated cardboard is one of the most popular recovered paperboard nowadays in recycled brown fiber utilization. (Paulapuro. 2000) OCC qualities fluctuate according to the geographical origin and over time. For example, manufacturers which consume OCC as raw material tend to use terms such as American OCC, Chinese OCC, and European OCC to specify the OCC origins because of the considerable quality differences in the same class. (Karänen & Retulainen. 2016)

During the audit, the line production was 1027 BDMTPD of testliner with 100g/m^2 basis weight. The raw material was a mixture of European OCC 70% and Chinese OCC 30%. Chinese OCC tend to have shorter fiber when compares with European OCC. With European OCC mixed, the retention of the pulp slurry was about 45% and ash content 20%.

2.3.2 End product properties

This testliner (shown in Picture 1) is making good quality industrial packaging paper to Chinese market. The machine is constructed of three layers in the wire section. The top layer of testliner is made up of hundred percent medium fiber while the medium and bottom layer made up of long fiber and short fiber mixture. It can be seen that the quality of end product is acceptable although there are still contaminants left in the pulp.

Picture 1. Top side of testliner

Stock preparation process has great effect on the paper physical properties. Table 1 is the laboratory test of paper samples. The laboratory tests were accomplished in TAMK. Tear strength and stiffness of the paper sample was tested in machine direction and cross-machine direction. On both directions, the paper has good tear strength but stiffness has significantly higher value on machine direction.

Table 1. Physical properties of the testliner

Tear strength,mN	MD	583
	CD	587
Stiffness,mNm	MD	0,688
	CD	0,373
Bursting strength,kPa		168
Roughness,ml/min	Top	629
	Bottom	691
Water absorption,g/m^2	Cobb60	2,71

2.3.3 Stock preparation process

The stock preparation process in the mill starts at pulper and ends at blending chest. Figure 4 illustrates the schematic process flow in stock preparation system, the energy efficiency is analyzed for the blue highlighted processes below.

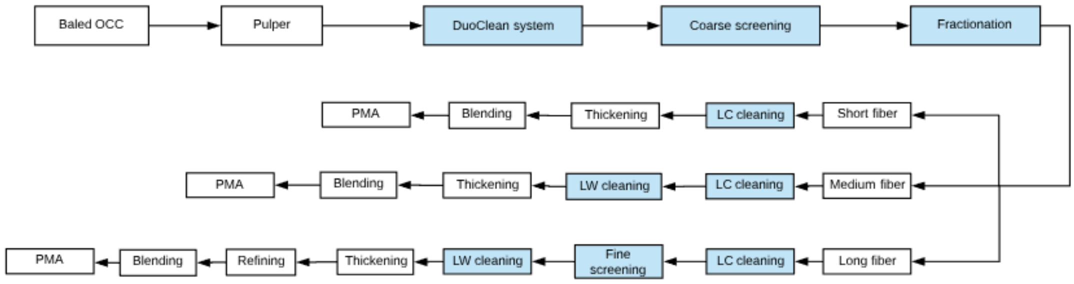

Figure 4. Stock preparation process schematic diagram

DuoClean system which is also called HD cleaning is the first separation process in this stock preparation, it consists of 2 stages with 3 cleaners in the first stage and 2 cleaners in the second stage. First stage cleaners in HD cleaning are continuous rejecting and second stage cleaners have intermittent rejecting. Then coarse screening is followed to remove large sized contaminants. The operation consistency for DuoClean and coarse screening was around 3%, and it was diluted to 2,3% at inlet of fractionation screen. In the fractionation process, fibers were sorted to short fibers, medium fibers and long fibers by their length, which were separated hereinafter to different cleaning processes.

Long fiber cleaning has more complex processes compared to medium fiber and short fiber. But all these three pulp streams have low consistency cleaning. Low consistency cleaning in the process is used to remove heavy particles such as sand, while light weight cleaning is used to remove light particles such as styrofoam. When the cleaning process for each steam is done, the thickened pulp is fed to blending chest before final preparation for paper machine in the approach system.

3 MEASUREMNETS IN STOCK PREPARATION

The focus on this chapter is to illustrate the parameters required in order to calculate the energy efficiency in the production line. All the equations used for the calculations are listed. For each sub-section, there will be one calculation example presented. The complete data is shown in chapter 4.

3.1 Measurement of pumping system efficiency

Pumping systems (Picture 2) consist of the pumps, piping, motors, valves and instrumentations. Worldwide industrial energy consumption is growing continuously and is expected to increase by 42% between the year 2007 and 2035. Pumping systems account for more than 20% of the world's electrical energy consumption. In certain energy intensity industries, the operation of pumping systems can be responsible for up to 90% of the energy usage. The initial invest for a pump takes only 5% of the whole life cycle cost, while pump maintenance and operation energy cost 95% of it. Using the right pumping system for a specific application is essential to reduce the totally cost. And this can be achieved by maximize the pump efficiency and minimize all possible losses in the pumping system. (RISI.2016)

Picture 2. Andritz pumps in stock preparation

In a pumping system, the role of the pump is to supply sufficient pressure to overcome the operating pressure to move stock at desired flow rate. Total dynamic head (TDH) is introduced to illustrate how much hydraulic power does stock should be imparted by the pump to reach desired level. (The Royal Academy of Engineering. 2014) The height to which the pump can raise the stock is the pump static head. In this studied case, TDH of cleaner and screen pump is the sum of static head (e.g. from pulp source top level to cleaner feed manifold), head loss because of friction and valves, and pressure head (e.g. cleaner pressure drop and cleaner accept pressure).

A motor transfers electrical energy to mechanical energy in the pulp. Actual motor power load reflects the energy consumption of a pump. However, the pump originally designed for the initial application purpose which may change in the later utilization. Thus in order to see if the pump is running at optimum efficiency, evaluation of optimized pump shaft power is required. Equation (1) below is the calculation of actual motor power input:

$$P_{motor,A} = \frac{I_{motor,A}}{I_{motor,R}} * P_{motor,N} \tag{1}$$

where:

$P_{motor,A}$: actual motor power input, kW

$I_{motor,A}$: actual motor ampere, A

$I_{motor,R}$: rated motor ampere, A

$P_{motor,N}$: nominal motor power, kW

Friction head loss caused by pipe and elbows can be assessed from the graph in appendix 1. Although the atmospheric pressure changes over height, it is so small in the pumping system and can be considered negligible. (The Royal Academy of Engineering. 2014) The operating pressure of a pumped system (screens and cleaners in this case) is calculated in meters. So, for a pumping system, the total dynamic head is defined as:

$$TDH = H_{static} + H_{valves} + H_{friction} + H_{\Delta P} + H_{accept\ pressure} \tag{2}$$

where:

TDH : total dynamic head, m

H_{Static} : static head, m

H_{valve} : valves head loss, m

$H_{friction}$: friction head loss, m

$H_{\Delta P}$: pressure drop head, m

$H_{accept\ pressure}$: accept pressure head, m

Pump shaft power is determined by process flow rate, total dynamic head and pump efficiency. Pulp flow rate data was collected from DCS control system in this OCC line. The pump efficiency in this study was supported by Andritz Oy. With the known total dynamic head and optimized pump efficiency, the pump shaft power required by the process can be calculated according to equation (3):

$$P_{shaft,O} = \frac{\rho_{pulp} * Q * TDH}{1020 * \eta_{pump,O(\%)}} \tag{3}$$

where:

$P_{shaft,O}$: optimized pump shaft power, kW

ρ_{pulp} : pulp density, which is 1000kg/m^3

Q : pulp flow rate, L/s

TDH : total dynamic head, m

$\eta_{pump,O}$: optimized pump efficiency, %

As discussed above, motor transfers power to pump shaft. However, motor cannot run at a 100% efficiency. Power input to motor for the optimized shaft power can be calculated as follows:

$$P_{motor,O} = \frac{P_{shaft,O}}{\eta_{motor,O}} \tag{4}$$

where:

$P_{motor,O}$: optimized pump motor power, kW

$P_{shaft,O}$: optimized pump shaft power, kW

$\eta_{motor,O}$: optimized pump motor efficiency, %

Calculation example (Coarse screening first stage feed pump):

Coarse screening is the first screening process studied in stock preparation system, where actual motor power (Table 2) is calculated as follows:

$$P_{motor,A} = \frac{I_{motor,A}}{I_{motor,R}} * P_{motor,N} = \frac{14A}{20A} * 280kW = 196kW$$

This pump has a design total dynamic head of 30 meters, however, the actual required TDH is lower (Table 5):

$$TDH = H_{static} + H_{valves} + H_{friction} + H_{\Delta P} + H_{accept\,pressure} = -8{,}4m + 5m + 0{,}74m + 2{,}6m + 15m = 14{,}96m$$

As total dynamic head required to raise the pulp to coarse screening first stage changed, the shaft power (Table 6) used by the pump in order to lift the stock can be calculated as:

$$P_{shaft,O} = \frac{\rho_{pulp} * Q * TDH}{1020 * \eta_{pump,O(\%)}} = \frac{1000\frac{kg}{m^3} * 667{,}5\frac{L}{s} * 14{,}96m}{1020 * 76{,}6(\%)} = 127{,}8kW$$

Power input to motor is calculated as (Table 6):

$$P_{motor,O} = \frac{P_{shaft,O}}{\eta_{motor,O}} = \frac{127{,}8W}{90\%} = 142kW$$

As calculated above, the power input to motor is 142 kW in optimized situation. When comparing optimized power to actual input power196 kW, it is possible to save 54 kW in this pump.

3.2 Measurement of screen motor efficiency

The pump motor load and screen motor load has the same calculation principle, shown as equation (5). Actual screen motor load is assessed by on-site ampere meter reading divided by rated ampere:

$$\eta_{screen\,motor} = \frac{I_{motor,A}}{I_{motor,R}} * 100\% \quad (5)$$

where:

$\eta_{screen\,motor}$: actual screen motor load, %

$I_{motor,A}$: actual ampere reading, A

$I_{motor,R}$: rated ampere, A

Calculation example (Coarse screening first stage):

The screen motor load is:

$$\eta_{screen\,motor} = \frac{I_{motor,A}}{I_{motor,R}} * 100\% = \frac{18{,}07A}{21{,}6A} * 100\% = 83{,}7\%$$

As it can be seen in the calculation, the coarse screening first stage screen motor in running at 83,7% load which means actual power consumption is 263,5 kW instead of 315 kW (Table 3).

3.3 Measurement of production efficiency

In this case study, production efficiency is assessed by the total energy consumption in each process that used to handle one ton bone dry pulp slurry. The actual feed flow rate and feed consistency is acquired in order to get BDMTPD for each process. Screen feed flow rate can be obtained from DCS system and cleaner feed flow rate can be found from cleaner capacity curve. If cleaner pressure drop deviates from nominal feed flow than actual flow rate, then actual flow rate can be calculated as follows:

$$Q_{feed,A} = \sqrt{\frac{\Delta P_A}{\Delta P_N}} * Q_{feed,N} \tag{6}$$

where:

$Q_{feed,A}$: actual feed flow rate, L/min

$Q_{feed,N}$: nominal feed flow rate, L/min

ΔP_A : actual pressure drop, kPa

ΔP_N : nominal pressure drop, kPa

Production is calculated as:

$$BDMTPD = \frac{Q_{feed,A}\frac{L}{min}*60\frac{min}{h}*24\frac{h}{d}*\frac{m^3}{1000L}*\rho\frac{kg}{m^3}}{1000kg/ton} * consistency \tag{7}$$

where:

$Q_{feed,A}$: actual feed flow rate, L/min

ρ_{pulp} : pulp density, which is1000kg/m^3

Calculation example (HD cleaning system):

HD cleaning system actual feed flow rate (shown in Appendix 2) is:

$$Q_{feed,A} = \sqrt{\frac{\Delta P_A}{\Delta P_N}} * Q_{feed,N} = \sqrt{\frac{131{,}5kPa}{172kPa}} * \frac{14006L}{min} = 12248\,\frac{L}{min}$$

With the actual feed flow rate, daily handling capacity of DuoClean system can be calculated as:

$$BDMTPD = \frac{Q_{feed,A}*60\frac{min}{h}*24\frac{h}{d}*\frac{m^3}{1000L}*\rho\frac{kg}{m^3}}{1000kg/ton} * consistency =$$

$$\frac{12176\frac{L}{min}*60\frac{min}{h}*24\frac{h}{d}*\frac{m^3}{1000L}*1000\frac{kg}{m^3}}{\frac{1000kg}{ton}} * 2{,}92\% = 515{,}4\;ton$$

Since there are 3 cleaners in DuoClean first stage, the total handling amount is 1546 ton. As shown in Table 4, the daily actual energy consumption of DuoClean system including both two stages is 12154 kWh/d. So 7,9 kWh energy is consumed in order to handle 1 ton bone dry pulp.

4 ENERGY EFFICIENCY IN STOCK PREPARATION

All the data tables listed in this chapter were calculated according to the mathematical formulas described in chapter 3. In the studied stock preparation process, energy was consumed by pumps and screen motors. Pumping system energy efficiency was not only affected by the pump efficiency, but also by motor efficiency. This paper did not include theoretical pump efficiency calculation. The pump efficiency information was supported by Andritz Oy.

Screen energy consumption was the sum of corresponding pump and screen motor energy requirement. With the pumps' and screens' energy consumption, the production efficiency of each process could be assessed. In this chapter, the actual power consumption of pump and screen motors are presented in section 4.1. Optimized power consumption is presented in section 4.2.

4.1 Data analyses

The data of 9 production processes which includes 24 pumps and 12 screens are listed in this section. It includes the design and actual power consumption of pump motors and screen motors, as well as the total power consumption and handling capacity of each separation process.

4.1.1 Pumping system power consumption

Table 2 is showing the actual power consumption in studied OCC stock preparation. Some of the motors are running at high loads and some at low loads. The highest motor load 92,8% was found in long fiber light weight cleaning first stage, which means motor is little undersized. Short fiber low consistency cleaning first stage feed pump motor which had a work load of 91,3% was also undersized. The lowest motor load 60% was found in HD cleaning first stage. Typical operating loads should be in range of 80%-85%. As shown in Table 2, most of the pump motors operated with moderate load.

Table 2. Actual operating power consumption of pumps

PUMPS	Design data		Actual data		
Position	Motor, kW	Rated$_{amp}$, A	Actual$_{amp}$, A	Motor load	Motor, kW
HD cleaning 1st stage	630	42,3	25,4	60,0 %	378,3
HD cleaning 2nd stage	160	286	229	80,1 %	128,1
Coarse screening 1st stage	280	20	14	70,0 %	196,0
Coarse screening 2nd stage	132	239	190	79,5 %	104,9
Coarse screening 3rd stage	90	165	127	77,0 %	69,3
#1 Fractionation	450	34	27,7	81,5 %	366,6
#2 Fractionation	280	20,1	17,35	86,3 %	241,7
SF LC cleaning 1st stage	250	18,5	16,89	91,3 %	228,2
SF LC cleaning 2nd stage	90	165	118	71,5 %	64,4
SF LC cleaning 3rd stage	45	83,7	60	71,7 %	32,3
MF LC cleaning 1st stage	250	18,5	16,26	87,9 %	219,7
MF LC cleaning 2nd stage	75	138	99	71,7 %	53,8
MF LC cleaning 3rd stage	45	83,7	64,8	77,4 %	34,8
MF LW cleaning 1st stage	250	18,5	16,13	87,2 %	218,0
MF LW cleaning 2nd stage	37	69	52	75,4 %	27,9
LF LC cleaning 1st stage	315	24	20	83,3 %	262,5
LF LC cleaning 2nd stage	132	239	200	83,7 %	110,5
LF LC cleaning 3rd stage	110	199	149	74,9 %	82,4
LF LC cleaning 4th stage	75	138	105	76,1 %	57,1
LF LC cleaning 5th stage	75	138	99	71,7 %	53,8
LF fine screening 2nd stage	75	138	85	61,6 %	46,2
LF fine screening 3rd stage	37	69	45	65,2 %	24,1
LF LW cleaning 1st stage	280	20,1	18,66	92,8 %	259,9
LF LW cleaning 2nd stage	37	69	57	82,6 %	30,6

4.1.2 Screen power consumption

Screening processes include both pumping energy consumption and screen motor energy consumption. Together they consume more energy than cleaner systems. Power consumption of motors are presented in Table 3. Coarse screening first stage and long fiber fine screening third stage screen motors were operating at a desired motor load. However, other screen motors were slightly oversized.

Table 3. Actual operating power consumption of screen motors

SCREEN MOTORS	Design data		Actual data		
Position	Motor, kW	Rated$_{amp}$, A	Actual$_{amp}$, A	Motor load	Motor, kW
Coarse screening 1st stage	315	21,6	18,07	83,7 %	263,5
Coarse screening 2nd stage	250	17,5	12,99	74,2 %	185,6
Coarse screening 3rd stage	110	205	105	51,2 %	56,3
#1 Fractionation(1)	160	291	189	64,9 %	103,9
#1 Fractionation(2)	160	291	184	63,2 %	101,2
#1 Fractionation(3)	160	291	185	63,6 %	101,7
#2 Fractionation(4)	160	291	190	65,3 %	104,5
#2 Fractionation(5)	160	291	185	63,6 %	101,7
LF fine screening 1st stage-1	132	243	130	53,5 %	70,6
LF fine screening 1st stage-2	132	243	175	72,0 %	95,1
LF fine screening 2nd stage	132	250,8	160	63,8 %	84,2
LF fine screening 3rd stage	90	165	131	79,4 %	71,5

4.1.3 Production energy efficiency

Energy consumption for centrifugal cleaning was totally by the feed pumps. This table assessed the average energy consumption for each process when handling one ton bone dry pulp. The calculated bone dry metric ton per day value consisted of non-fibrous materials and fibers fed to each processes. As shown in Table 4, fractionation process had the highest energy consumption in order to separate one ton bone dry pulp, and then followed by long fiber fine screening.

Table 4. Actual production efficiency of each separation processes

	Energy Consumption, kWh/day	BDMTPD	Energy Efficiency, kWh/ton production
HD cleaning	12154	1546	7,86
Coarse screening	21016	1623	12,95
Fractionation	26911	1416	19,00
SF LC cleaning	7797	448	17,40
MF LC cleaning	7401	833	8,88
MF LW cleaning	5900	556	10,61
LF LC cleaning	10438	900	11,60
LF fine screening	12550	665	18,87
LF LW cleaning	6972	548	12,72
Total	111139	-	-

The total energy consumption for cleaning and screening was 111139 kWh/d (Table 4), based on production amount of 1027 BDMTPD. Energy consumed by the separation processes accounted for 108 kWh/ton. When comparing with total energy consumption 150kWh/ton in stock preparation, separation processes represent 72% of it.

4.2 Energy saving potential

It requires flowrate, pump head calculation and pump curve to check if the pump is properly sized for the existing operating condition. Static head and actual process flow rate data was collected during the on-site research, however, the optimized pump head need to be accessed accordingly. The yellow highlighted cells in Table 5 are the valve losses need to be taken into consideration. Accept pressure head is not always considered when calculate pump head, for example, when the stock is sent to a thickener. There are

8 processes had high accept pressure and 14 processes had high pressure drop that can be lowered to reduce energy consumption.

Table 5 Optimized total dynamic head

	Static height	Valve head, m				Pipe loss	ΔP	ΔP,New	Accept pressure	Accept P, NEW	Opt. TDH
PUMP HEADS	m	Feed (A)	Feed (M)	Feed (new)	Accept	m	m	m	m	m	m
HD cleaning 1st stage	7,58	2	2			1,59	13,15		13,95		26,32
HD cleaning 2nd stage	11,58	2	4	1		0,57	18,67		4,18		33,82
Coarse screening 1st stage	-8,4	1	3	1	3	0,74	2,60		17,40	15,00	14,96
Coarse screening 2nd stage	0,9	1	5	1	4	0,20	3,30		28,10	15,00	25,40
Coarse screening 3rd stage	8,3		3	1	6	1,74	4,52		23,04	15,00	39,56
#1 Fractionation	6,6		5	1		0,77	1,32		22,92	15,00	24,69
#2 Fractionation	6,6		5	1		0,95	2,80		21,00	15,00	26,35
SF LC cleaning 1st stage**	9,8	1	1		2	0,20	21,20	13,80	10,20		27,80
SF LC cleaning 2nd stage	9,8	1	4		3	0,18	13,30		13,00		31,28
SF LC cleaning 3rd stage	6,3	1	1		1	0,62	14,50	13,80	3,00		26,72
MF LC cleaning 1st stage**	9,8	1	1		1	0,28	23,25	13,80	6,44		26,88
MF LC cleaning 2nd stage	-1,1	1	1		2	0,33	16,97	13,80	7,90		24,92
MF LC cleaning 3rd stage	6	1	1		2	0,76	15,59	13,80	8,10		32,66
MF LW cleaning 1st stage**	9,8	1	4	2	2	0,65	16,67	10,00	7,84		25,45
MF LW cleaning 2nd stage	5,6	1	4	2	2	0,81	18,85	10,00	7,17		21,41
LF LC cleaning 1st stage*	0,9	1	2		2	0,15	17,00	13,80	16,60		34,18
LF LC cleaning 2nd stage	0	1	2		2	0,32	16,60	13,80	4,30		23,42
LF LC cleaning 3rd stage	0	1	3		2	0,19	14,30	13,80	5,80		25,79
LF LC cleaning 4th stage	0	1	2		2	0,21	14,40	13,80	5,10		24,11
LF LC cleaning 5th stage	6	1	2		2	0,81	17,50	13,80	2,00		27,61
LF fine screening 1st stage	0,9		4	1	3		3,33		17,50	10,00	
LF fine screening 2nd stage	0,3	1	5	1	4	0,44	3,02		25,31	15,00	24,76
LF fine screening 3rd stage	5,8	1	4	1	5	0,54	0,86		26,67	15,00	29,20
LF LW cleaning 1st stage**	9,8	1	4	2	2	0,69	18,92	10,00	5,11		25,49
LF LW cleaning 2nd stage	5,6	1	1		2	0,89	18,04	10,00	3,32		23,81

*pump also supply to LF fine screening 1st stage
**pump also supply to thickener

With the known flow rate, optimized pump head, the pump efficiency was obtained. When checking the pump curve, it was found that HD cleaning first stage, coarse screening second and third stage, and long fiber fine screening third stage pumps operating at a low efficiency. However, it was possible to replace the above mentioned 4 pumps to increase the efficiency. For example, coarse screening second stage pump running at 68,4% efficiency with the existing pump, but the efficiency will raise up to 84,4% (Table 6) when changed to another.

Additionally, there are 7 impellers can be changed to a smaller size. All those changes in pumps would lead to a lower shaft power consumption, thus result a lower motor input. After optimization, there are 10 pumps could run over 80% efficiency while other pumps run at the efficiency range of 70%-80%.

Table 6. Optimized pump and pump motor efficiency

	Q		H		Pump eff.	Pump, $P_{shaft,O}$	Motor eff.	Motor, $P_{input,O}$
PUMPS	**l/min**	**l/s**	**m**	**ft**	**%**	**kW**	**%**	**kW**
HD cleaning 1st stage	36744	612,4	26,3	86,4	90,1	175,4	90,0	194,9
HD cleaning 2nd stage	9886	164,8	33,8	111,0	78,5	69,6	90,0	77,3
Coarse screening 1st stage	40047	667,5	15,0	49,1	76,6	127,8	90,0	142,0
Coarse screening 2nd stage	11460	191,0	25,4	83,3	84,4	56,4	95,0	59,3
Coarse screening 3rd stage	2086	34,8	39,6	129,8	75,6	17,8	95,0	18,8
#1 Fractionation	49042	817,4	24,7	81,0	83,1	238,0	90,0	264,5
#2 Fractionation	32650	544,2	26,4	86,5	79,8	176,2	90,0	195,7
SF LC cleaning 1st stage	37794	629,9	27,8	91,2	82,9	207,1	90,0	230,1
SF LC cleaning 2nd stage	10461	174,4	31,3	102,6	82,2	65,0	95,0	68,5
SF LC cleaning 3rd stage	4223	70,4	26,7	87,6	76,7	24,0	93,9	25,6
MF LC cleaning 1st stage	36885	614,8	26,9	88,2	82,6	196,1	90,0	217,9
MF LC cleaning 2nd stage	10503	175,1	24,9	81,8	83,6	51,2	94,7	54,0
MF LC cleaning 3rd stage	4223	70,4	32,7	107,2	72,4	31,1	93,9	33,2
MF LW cleaning 1st stage	33269	554,5	25,4	83,5	78,4	176,5	90,0	196,1
MF LW cleaning 2nd stage	3734	62,2	21,4	70,2	78,5	16,6	93,6	17,8
LF LC cleaning 1st stage	34167	569,5	34,2	112,1	83,8	227,7	90,0	253,0
LF LC cleaning 2nd stage	19479	324,6	23,4	76,8	77,2	96,5	95,4	101,2
LF LC cleaning 3rd stage	13630	227,2	25,8	84,6	73,6	78,1	95,4	81,8
LF LC cleaning 4th stage	10522	175,4	24,1	79,1	83,1	49,9	94,7	52,7
LF LC cleaning 5th stage	6959	116,0	27,6	90,6	73,2	42,9	90,0	47,7
LF fine screening 2nd stage	6709	111,8	24,8	81,2	71,6	37,9	94,7	40,0
LF fine screening 3rd stage	1769	29,5	29,2	95,8	75,2	11,2	95,6	11,7
LF LW cleaning 1st stage	41886	698,1	25,5	83,6	83,0	210,2	90,0	233,5
LF LW cleaning 2nd stage	4566	76,1	23,8	78,1	76,8	23,1	93,6	24,7

There were totally 24 pumps and 12 screens consuming energy in the studied OCC line. Screening energy efficiency improvement is not considered in this study although it is possible to save energy in screening by changing screen internal parts such as rotors. Saving could be in range of 15% - 20%.

As it could be seen in Table 7, actual total pumping consumption is 3291 kWh while screens consume 1339,8 kWh. HD cleaning first stage feed pump had the most significant power saving potential, then followed by first stage fractionation screen feed pump. With these two stage feed pumps, 285 kW could be saved after optimization.

As calculated, optimized system has a potential to save energy 649 kWh which reduces production energy consumption from 108 kWh/ton to 93 kWh/ton. The average cost of electricity is 6,4 cents/kWh. Based on this cost and 350 operating days per year, over 300 thousand euro could be saved annually. This result is upon the optimized conditions with pump motors running at the highest efficiency.

Table 7. Energy cost saving in optimized situation

Pump Energy Efficiency	Actual(kW)	Optimized(kW)
HD cleaning 1st stage	378,3	194,9
HD cleaning 2nd stage	128,1	77,3
Coarse screening 1st stage	196,0	142,0
Coarse screening 2nd stage	104,9	59,3
Coarse screening 3rd stage	69,3	18,8
#1 Fractionation	366,6	264,5
#2 Fractionation	241,7	195,7
SF LC cleaning 1st stage	228,2	230,1
SF LC cleaning 2nd stage	64,4	68,5
SF LC cleaning 3rd stage	32,3	25,6
MF LC cleaning 1st stage	219,7	217,9
MF LC cleaning 2nd stage	53,8	54,0
MF LC cleaning 3rd stage	34,8	33,2
MF LW cleaning 1st stage	218,0	196,1
MF LW cleaning 2nd stage	27,9	17,8
LF LC cleaning 1st stage	262,5	253,0
LF LC cleaning 2nd stage	110,5	101,2
LF LC cleaning 3rd stage	82,4	81,8
LF LC cleaning 4th stage	57,1	52,7
LF LC cleaning 5th stage	53,8	47,7
LF fine screening 2nd stage	46,2	40,0
LF fine screening 3rd stage	24,1	11,7
LF LW cleaning 1st stage	259,9	233,5
LF LW cleaning 2nd stage	30,6	24,7
Total pumps power consumption	**3291,0**	**2642,1**

Screen motor Energy Efficiency	Actual(kW)	Optimized(kW)
Coarse screening 1st stage	263,5	263,5
Coarse screening 2nd stage	185,6	185,6
Coarse screening 3rd stage	56,3	56,3
#1 Fractionation(1)	103,9	103,9
#1 Fractionation(2)	101,2	101,2
#1 Fractionation(3)	101,7	101,7
#2 Fractionation(4)	104,5	104,5
#2 Fractionation(5)	101,7	101,7
LF fine screening 1st stage-1	70,6	70,6
LF fine screening 1st stage-2	95,1	95,1
LF fine screening 2nd stage	84,2	84,2
LF fine screening 3rd stage	71,5	71,5
Total motors power consumption	**1339,8**	**1339,8**

Total Power Consumption	4630,8	3981,8
	kW savings →	**649,0**

Energy cost	0,064	€/kWh

Savings	Oper. d/a	€/a
Energy savings	350	348 886

5 DISCUSSION

OCC is utilized as common raw material in China in packaging paperboard production. Due to the lacking of virgin fiber resources, the recycled fiber in Chinese market is up to 80% of total fiber consumption since 2015 and is still expected to grow in the near future. Unlike virgin fiber, recycled fiber contains large amount of contaminants which can deteriorate paper quality. In order to meet defined fiber criteria, stock preparation is introduced to separate the non-fibrous material.

Stock preparation process is widely applied in recycled fiber process to get desired pulp slurry. Separation processes in stock preparation are screening, centrifugal cleaning and fractionation. To be more specific, 2 screening processes, 1 fractionation process and 6 centrifugal cleaning processes were studied in this paper.

Like other processes in the pulp and paper mill, stock preparation consumes large amount of energy. At existing mills, about 20% of installed centrifugal pumps offer the potential cost savings (Pemberton. 2016). Consequently, energy efficiency improvement to pumps can lead to significant energy savings.

In this study it was found that not all the analyzed pumps were running at optimized condition. In the analyzed 24 pumps, the total actual energy consumption was 3291 kWh. Energy efficiency of pumps could be improved by about 20% at optimized conditions. Screen motors were another energy consumer in the analyzed processes. Nearly 1400 kWh were consumed by 12 screens in stock preparation.

All the energy consumed by the pumps and screens were utilized to separate pulp slurry from non-fibrous materials such as sand, metal, glue which came from the raw material directly. It would be desirable that the raw material entering the mill would be handled and storage so that it was as clean as possible, which is a challenge in many cases.

As a result of this thesis work, it was discovered that there is an opportunity to save energy in the screening and centrifugal cleaning processes in the studied OCC stock preparation line. Also in general if line production is something else than original design, then there is an opportunity for optimization. Reducing energy input to the system can not only reduce the cost, but also reduce the environmental burden.

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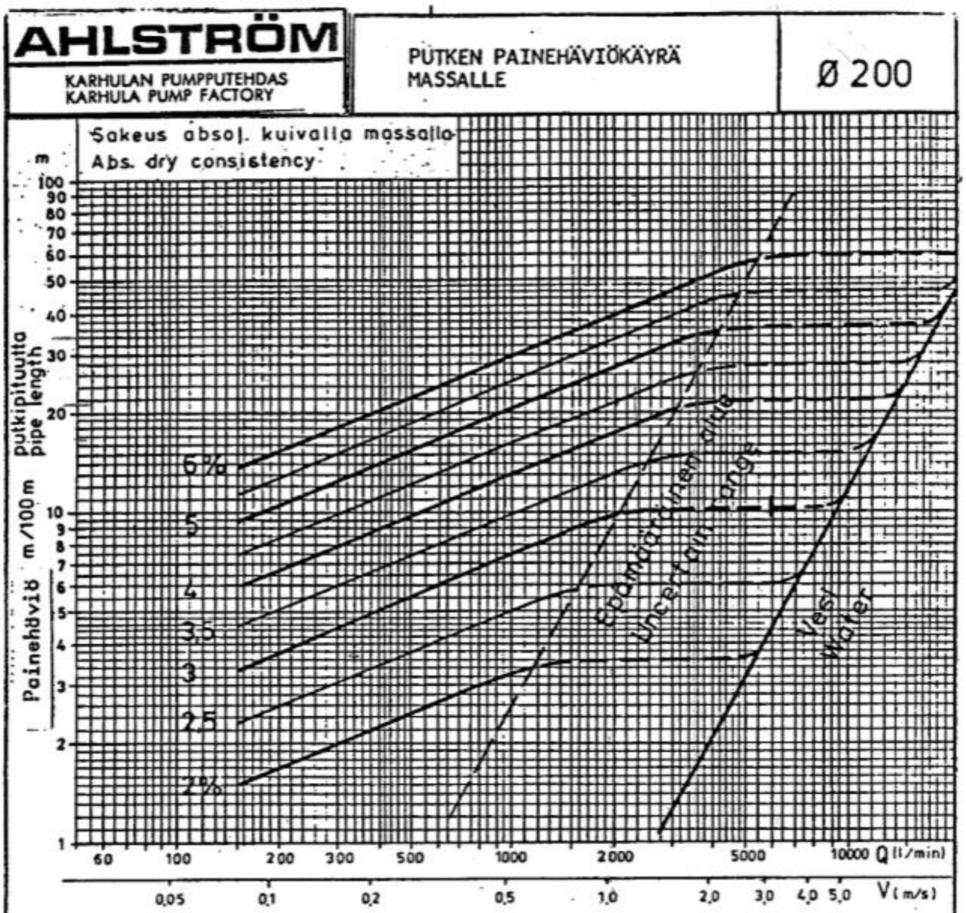
APPENDICES

Appendix 1. Pipe head loss



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu	0,90	Bleached
Sulfaatti	0,90	Sulphate
Hioke	1,40	Groundwood
Kraft-massa	1,20	Kraft (Canadian)
Jätepaperimassa	0,90	Reclaimed paper
Valkaisematon olki	0,50	Unbleached straw
Valkaistu	0,90	Bleached

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

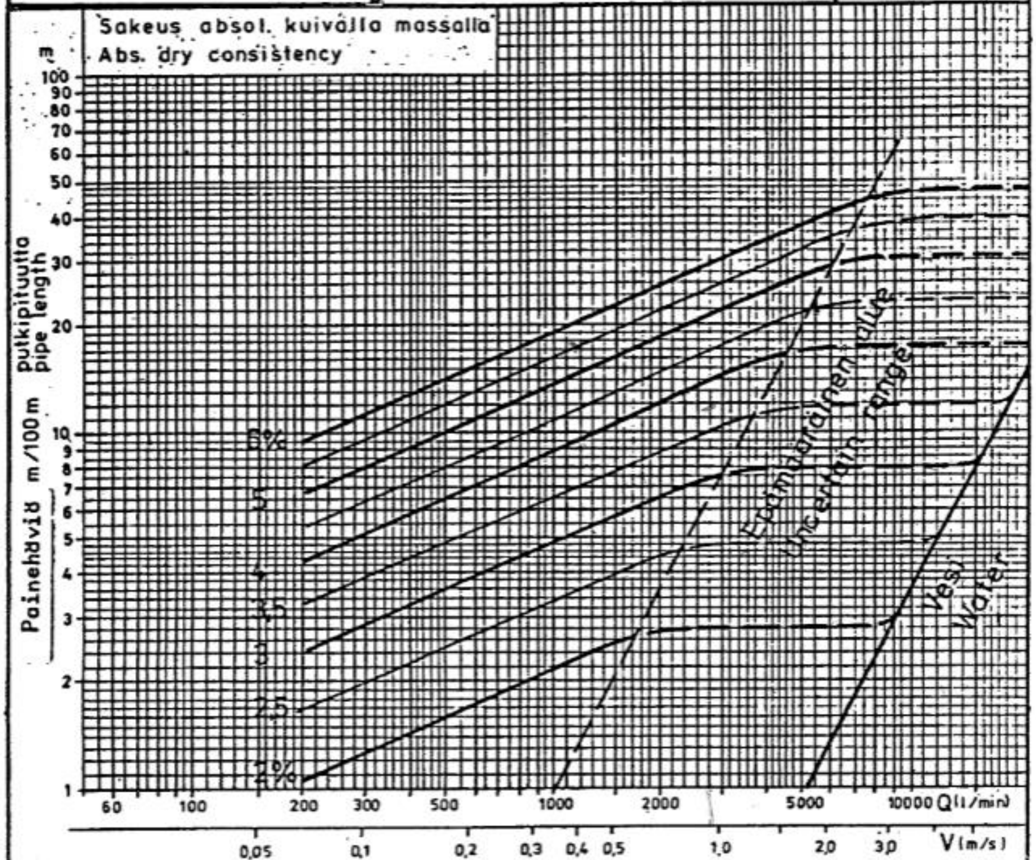
	90°				45°												D 2D				D D/2			
V m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1 %	0,6	1,2	2,0	2,8	0,6	1,0	1,6	2,2	0,8	1,6	4,8	6,6	0,4	0,4	0,6	0,6	0,4	0,3	0,2	0,0	0,4	2,0	4,4	6,0
2 %	0,4	0,7	1,2	1,8	0,4	0,6	1,0	1,6	0,6	0,8	3,6	5,0	0,4	0,4	0,6	0,6	0,3	0,2	0,1	0,0	0,4	0,8	2,8	4,0
3 %	0,4	0,4	0,8	1,2	0,4	0,4	0,6	1,2	0,4	0,7	2,2	3,2	0,4	0,4	0,6	0,6	0,3	0,2	0,0	0,0	0,4	0,4	1,8	2,4
4 %	0,4	0,4	0,4	0,8	0,4	0,4	0,4	0,8	0,4	0,6	1,0	2,6	0,4	0,4	0,6	0,6	0,3	0,2	0,0	0,0	0,4	0,4	0,8	1,6
5 %	0,4	0,4	0,4	0,6	0,4	0,4	0,4	0,6	0,4	0,5	0,8	1,6	0,4	0,4	0,4	0,4	0,2	0,2	0,0	0,0	0,2	0,4	0,4	1,0
6 %	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	1,2	0,4	0,4	0,4	0,4	0,2	0,2	0,0	0,0	0,2	0,2	0,4	0,6

Figure 5. 200mm diameter pipe head loss. (Ahlstorm. ND)

AHLSTRÖM
KARHULAN PUMPPUTEHDAS
KARHULA PUMP FACTORY

PUTKEN PAINEHÄVIÖKÄYRÄ MASSALLE

Ø 250



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu —··—	0,90	Bleached —··—
Sulfaatti	0,90	Sulphate
Hioke	1,40	Groundwood
Kraft-massa	1,20	Kraft (Canadian)
Jätepaperimassa	0,90	Reclaimed paper
Valkaisematon olki	0,50	Unbleached straw
Valkaistu —··—	0,90	Bleached —··—

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

	90°				45°												D 2D				D D/2			
V m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1/	0,8	1,5	2,5	3,5	0,8	1,3	2,0	2,8	1,0	2,0	6,0	8,3	0,5	0,5	0,8	0,8	0,5	0,4	0,3	0,0	0,5	2,5	5,5	7,5
2/	0.5	0,9	1.5	2,2	0.5	0,8	1.3	2,0	0,8	1,0	4.5	6,3	0.5	0,5	0,8	0,8	0,4	0,3	0,1	0,0	0,5	1,0	3,5	5.0
3/	0.5	0.5	1.0	1.5	0.5	0,5	0,8	1.5	0,5	0,9	2,8	4,0	0,5	0,5	0,8	0,8	0,4	0,3	0,0	0,0	0,5	0,5	2,2	3,0
4/	0,5	0,5	0,5	1,0	0,5	0,5	0,5	1,0	0,5	0,8	1,2	3,2	0,5	0,5	0,8	0,8	0,4	0,3	0,0	0,0	0,5	0,5	1,0	2,0
5/	0,5	0,5	0,5	0,8	0,5	0,5	0,5	0,8	0,5	0,6	1,0	2,0	0,5	0,5	0,5	0,5	0,2	0,3	0,0	0,0	0,3	0,5	0,5	1,5
6/	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1,5	0,5	0,5	0,5	0,5	0,2	0,3	0,0	0,0	0,3	0,3	0,5	0,8

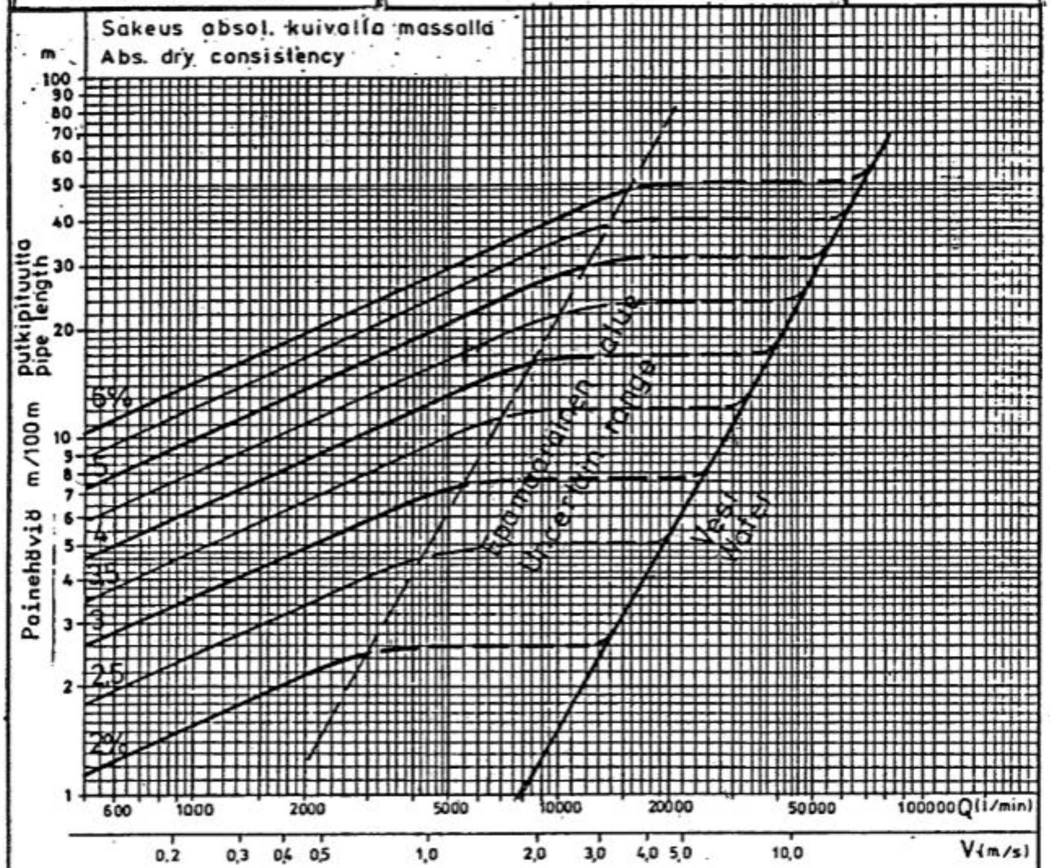
Figure 6. 250mm diameter pipe head loss. (Ahlstorm. ND)

AHLSTRÖM

KARHULAN PUMPPUTEHDAS
KARHULA PUMP FACTORY

PUTKEN PAINEHÄVIÖKÄYRÄ MASSALLE

Ø 300



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu —"—	0,90	Bleached —"—
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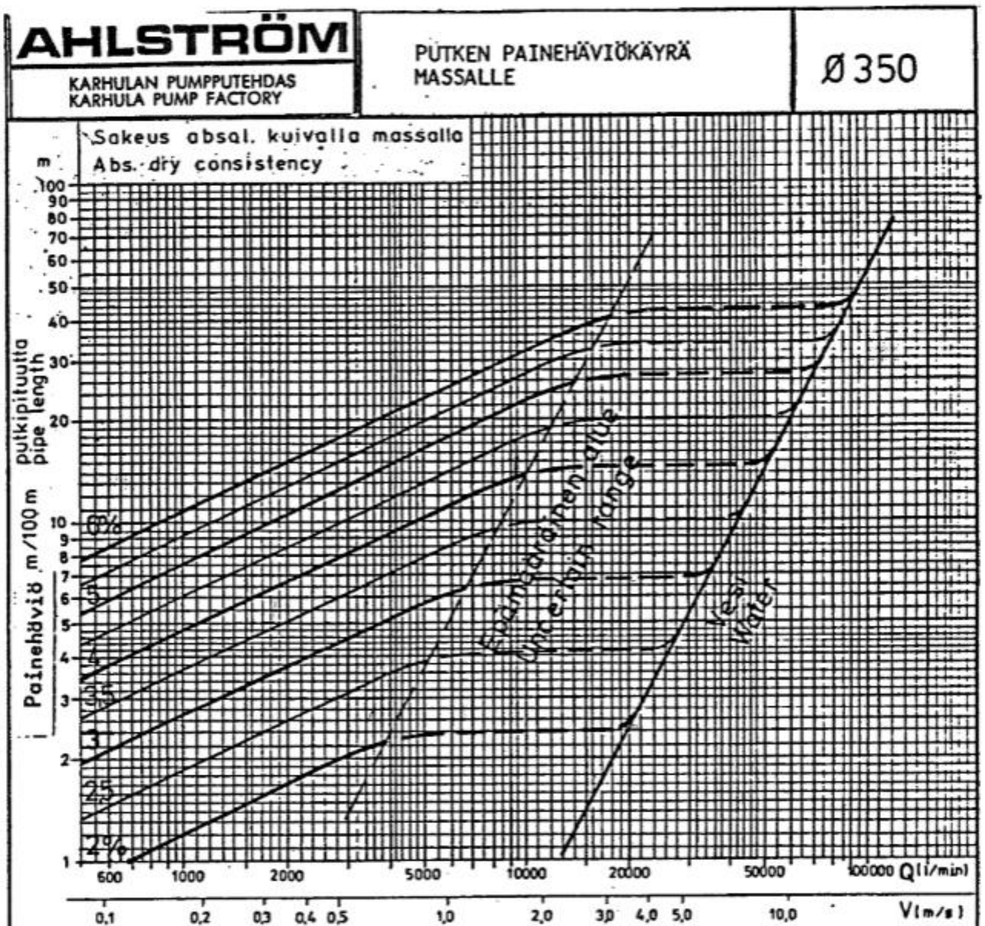
Valkaisematon olki	0,50	Unbleached straw
Valkaistu —"—	0,90	Bleached —"—

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

	90°				45°												D 2D				D D/2			
V m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1	0.9	1.8	3.0	4.2	0.9	1.5	2.4	3.3	1.2	2.4	7.2	9.9	0.6	0.6	0.9	0.9	0.6	0.5	0.3	0.0	0.6	3.0	6.6	9.0
2	0.6	1.0	1.8	2.7	0.6	0.9	1.5	2.4	0.9	1.2	5.4	7.5	0.6	0.6	0.9	0.9	0.5	0.3	0.2	0.0	0.6	1.2	4.2	6.0
3	0.6	0.6	1.2	1.8	0.6	0.6	0.9	1.8	0.6	1.0	3.3	4.8	0.6	0.6	0.9	0.9	0.5	0.3	0.0	0.0	0.6	0.6	2.7	3.6
4	0.6	0.6	0.6	1.2	0.6	0.6	0.6	1.2	0.4	0.9	1.5	3.9	0.6	0.6	0.9	0.9	0.5	0.3	0.0	0.0	0.6	0.6	1.2	2.4
5	0.6	0.6	0.6	0.9	0.6	0.6	0.6	0.9	0.4	0.8	1.2	2.4	0.6	0.6	0.6	0.6	0.3	0.3	0.0	0.0	0.3	0.6	0.6	1.5
6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.4	0.5	0.6	1.8	0.6	0.6	0.6	0.6	0.3	0.3	0.0	0.0	0.3	0.3	0.6	0.9

Figure 7. 300mm diameter pipe head loss. (Ahlstorm. ND)



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu —"—	0,90	Bleached —"—
Sulfaatti	0,90	Sulphate
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Valkaisematon olki	0,50	Unbleached straw
Valkaistu —"—	0,90	Bleached —"—

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

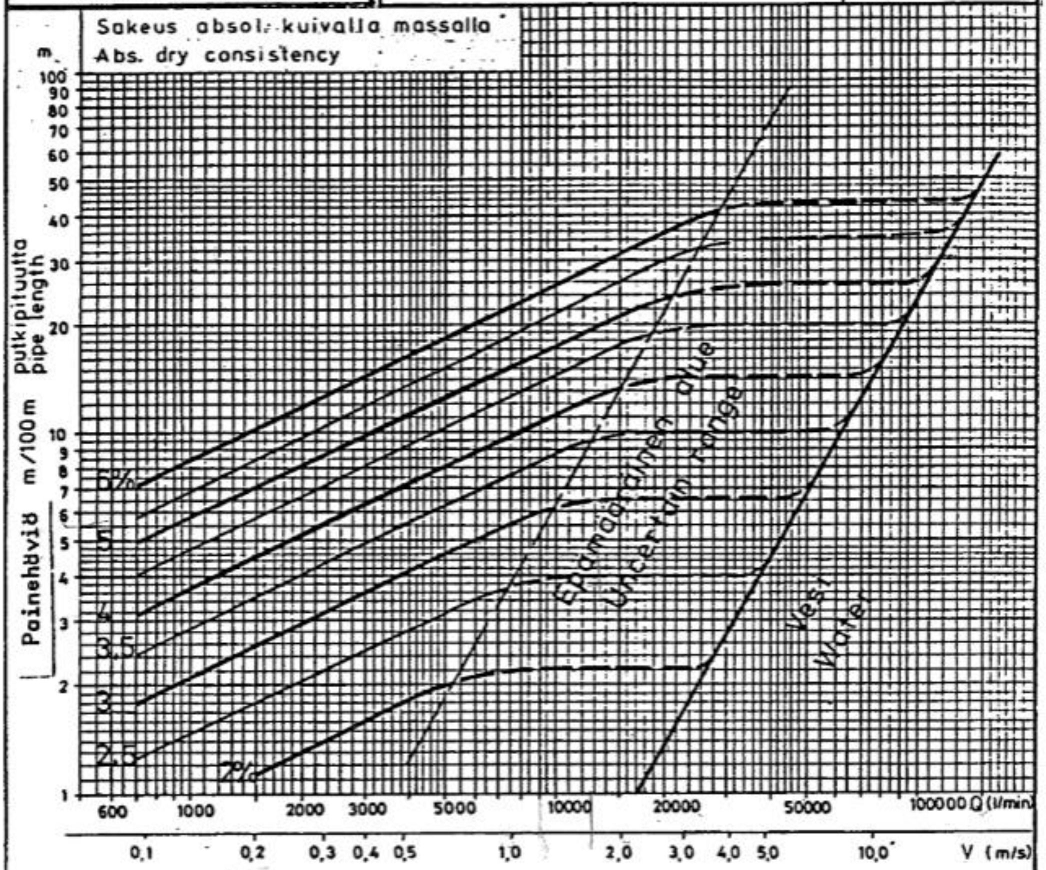
	90°				45°												D 2D				D D/2			
V m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1	1,0	2,1	3,5	4,9	1,0	1,8	2,8	3,8	1,4	2,8	8,4	11,5	0,7	0,7	1,0	1,0	0,7	0,5	0,4	0,0	0,7	3,5	7,7	10,5
2	0,7	1,2	2,1	3,2	0,7	1,0	1,8	2,8	1,0	1,4	6,3	8,7	0,7	0,7	1,0	1,0	0,5	0,4	0,2	0,0	0,7	1,4	4,9	7,0
3	0,7	0,7	1,4	2,1	0,7	0,7	1,0	2,1	0,7	1,2	3,8	5,6	0,7	0,7	1,0	10	0,5	0,4	0,0	0,0	0,7	0,7	3,1	4,2
4	0,7	0,7	0,7	1,4	0,7	0,7	0,7	1,4	0,7	1,0	1,8	4,5	0,7	0,7	1,0	1,0	0,5	0,4	0,0	0,0	0,7	0,7	1,4	2,8
5	0,7	0,7	0,7	1,0	0,7	0,7	0,7	1,0	0,7	0,9	1,4	2,8	0,7	0,7	0,7	0,7	0,4	0,4	0,0	0,0	0,4	0,7	0,7	2,1
6	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	0,7	2,1	0,7	0,7	0,7	0,7	0,4	0,4	0,0	0,0	0,4	0,4	0,7	1,0

Figure 8. 350mm diameter pipe head loss. (Ahlstorm. ND)

AHLSTRÖM
KARHULAN PUMPPUTEHDAS
KARHULA PUMP FACTORY

PUTKEN PAINEHÄVIÖKÄYRÄ MASSALLE

ϕ400



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu —··—	0,90	Bleached —··—
Sulfaatti	0,90	Sulphate
Hioke	1,40	Groundwood
Kraft-massa	1,20	Kraft (Canadian)
Jätepaperimassa	0,90	Reclaimed paper
Valkaisematon olki	0,50	Unbleached straw
Valkaistu —·—	0,90	Bleached —·—

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

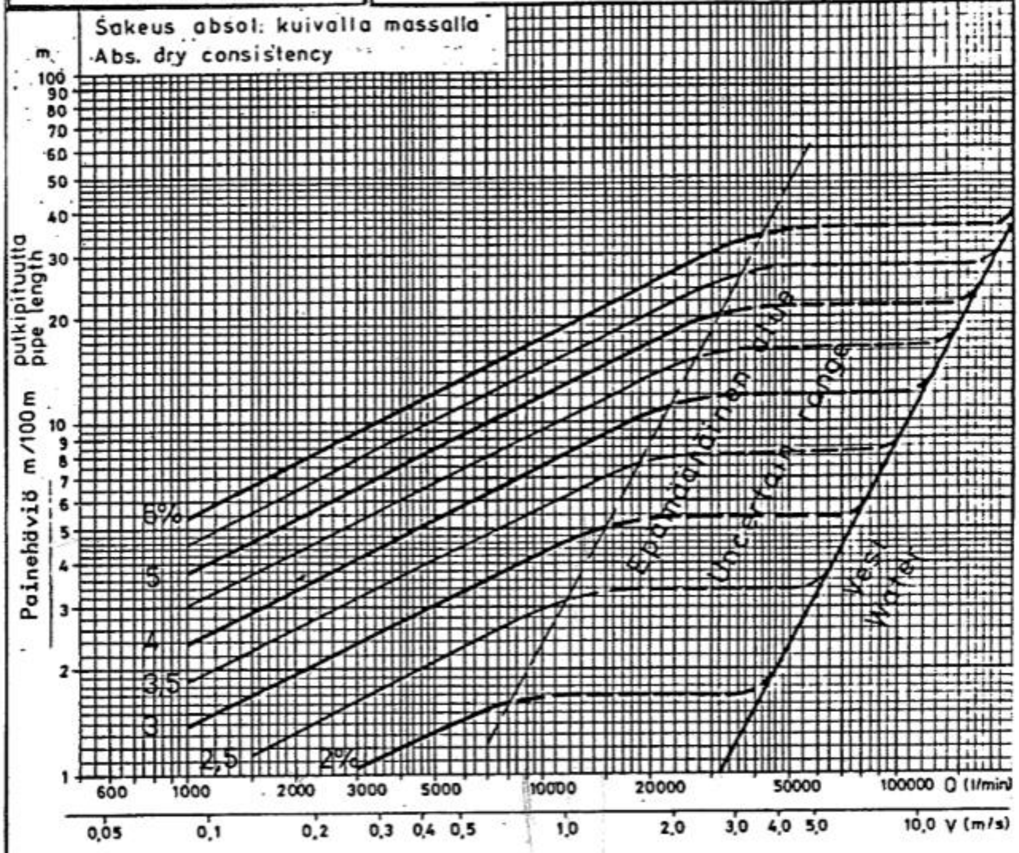
	90°				45°												D–2D				D–D/2			
v m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1 %	1,2	2,4	4,0	5,6	1,2	2,0	3,2	4,4	1,6	3,2	9,6	13,2	0,8	0,8	1,2	1,2	0,8	0,6	0,4	0,0	0,8	4,0	8,8	12
2 %	0,8	1,4	2,4	3,6	0,8	1,2	2,0	3,2	1,2	1,6	7,2	10	0,8	0,8	1,2	1,2	0,6	0,4	0,2	0,0	0,8	1,6	5,6	8
3 %	0,8	0,8	1,6	2,4	0,8	0,8	1,2	2,4	0,8	1,4	4,4	6,4	0,8	0,8	1,2	1,2	0,6	0,4	0,0	0,0	0,8	0,8	3,6	4,8
4 %	0,8	0,8	0,8	1,6	0,8	0,8	0,8	1,6	0,8	1,2	2,0	5,2	0,8	0,8	1,2	1,2	0,6	0,4	0,0	0,0	0,8	0,8	1,6	3,2
5 %	0,8	0,8	0,8	1,2	0,8	0,8	0,8	1,2	0,8	1,0	1,6	3,2	0,8	0,8	0,8	0,8	0,4	0,4	0,0	0,0	0,4	0,8	0,8	2,0
6 %	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8	2,4	0,8	0,8	0,8	0,8	0,4	0,4	0,0	0,0	0,4	0,4	0,8	1,2

Figure 9. 400mm diameter pipe head loss. (Ahlstorm. ND)

AHLSTRÖM
KARHULAN PUMPPUTEHDAS
KARHULA PUMP FACTORY

PUTKEN PAINEHÄVIÖKÄYRÄ
MASSALLE

ϕ 500



Korjauskerroin eri massalaaduille
Correction factor for various stocks

Valkaisematon sulfiitti	1,00	Unbleached Sulphite
Valkaistu ——"——	0,90	Bleached ——"——
Sulfaatti	0,90	Sulphate
Hioke	1,40	Groundwood
Kraft-massa	1,20	Kraft (Canadian)
Jätepaperimassa	0,90	Reclaimed paper
Valkaisematon olki	0,50	Unbleached straw
Valkaistu ——"——	0,90	Bleached ——"——

Ekvivalenttinen putkipituus metreissä — Equivalent length in meters

	90°				45°												D 2D				D D/2			
v m/s	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3	0,5	1	2	3
1%	1,5	3,0	5,0	7,0	1,5	2,5	4,0	5,5	2,0	4,0	12	16,5	1,0	1,0	1,5	1,5	1,0	0,8	0,5	0,0	1,0	5,0	11	15
2%	1,0	1,8	3,0	4,5	1,0	1,5	2,5	4,0	1,5	2,0	9	12,5	1,0	1,0	1,5	1,5	0,8	0,5	0,3	0,0	1,0	2,0	7	10
3%	1,0	1,0	2,0	3,0	1,0	1,0	1,5	3,0	1,0	1,8	5,5	8,0	1,0	1,0	1,5	1,5	0,8	0,5	0,0	0,0	1,0	1,0	4,5	6
4%	1,0	1,0	1,0	2,0	1,0	1,0	1,0	2,0	1,0	1,5	2,5	6,5	1,0	1,0	1,5	1,5	0,8	0,5	0,0	0,0	1,0	1,0	2	4
5%	1,0	1,0	1,0	1,5	1,0	1,0	1,0	1,5	1,0	1,3	2,0	4,0	1,0	1,0	1,0	1,0	0,5	0,5	0,0	0,0	0,5	1,0	1,0	2,5
6%	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	3,0	1,0	1,0	1,0	1,0	0,5	0,5	0,0	0,0	0,5	0,5	1,0	1,5

Figure 10. 500mm diameter pipe head loss. (Ahlstorm. ND)

Appendix 2. Operation condition of analyzed processes

Table 8. Operation pressure drop, feed flow rate and consistency of analyzed processes

	ΔP_N, kPa	ΔP_A, kPa	$Q_{feed,N}$ l/min	$Q_{feed,A}$ l/min	Consistency
HD cleaning	172	131,5	14006	12248	2,92 %
Coarse screening	-	-	-	40047	2,81 %
Fractionation	-	-	-	16080	2,32 %
SF LF cleaning	138	208	592	727	0,82 %
MF LC cleaning	138	232	592	768	1,57 %
MF LW cleaning	100	168	170	220	1,16 %
LF LC cleaning	138	170	592	657	1,83 %
LF fine screening	-	-	-	11049	2,09 %
LF LW cleaning	100	189	170	221	0,91 %